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1. Space Environmental Simulation-
   Where do we go from here?

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3. Objective: There now are in existence several facilities capable of simulating space environments for testing the larger space systems. If we follow present approaches, future systems will require even larger and more complex test facilities. Thus, two important problems which face us today undoubtedly will become even more precipitous tomorrow: that of physically accommodating complete full-scale systems in environmental test facilities and that of simulating (not duplicating) the environments to produce meaningful effects which can be related to those incurred by space operations. This paper explores what research must be done now to acquire the environmental technology needed for developing future space systems.

4. The limits of our present technology in simulating launch environments (vibration, shock, acoustical noise, transient pressures and heating) and space environments (hard vacuum, solar radiation, energic particle radiation, magnetic fields) are discussed. Advancements likely to result from work now under way are estimated as the basis of predicting voids which may occur in future technological needs for environmental simulation.

In the fields of noise and vibration, the basic theories of structural dynamics have become quite sophisticated and probably will develop in the normal course of events to meet future needs for structural design. Practical methods for handling mechanical impedance in testing and for dealing with non-stationary kinematics are being developed. However, the high energy, low frequency acoustic excitation anticipated from future propulsion systems may generate problems which are difficult to foresee since these environmental conditions never before have been produced by man or nature.

The techniques of combining environments to achieve fuller simulation of the launch environments (vibration, sustained acceleration, acoustic excitation, pressure changes) are being developed to a high degree. However, this approach inherently is size and weight limited in the practical sense although Goddard's Launch Phase Simulator will accommodate test specimens of ten feet in diameter by fifteen feet long weighing up to 4,000 pounds.

Thermal-vacuum testing techniques in the present state of the art are inadequate to predict conditions of thermal balance in space operations within acceptable tolerances. In some instances, unexplained discrepancies amount to as much as 20°C, parts of the spacecraft being that much hotter in space operation than anticipated. Solar lamps with improved spectral characteristics are being developed in an effort to improve simulation. Better measurement techniques also are needed and are being developed.

In solar simulation and vacuum testing, economics will enforce greater attention to separating the system effects from material effects. Certainly all the problems which can be solved in a materials laboratory must be eliminated as significant factors in testing large full scale space systems in giant environmental chambers. Thus, work is underway to categorize environmental effects on space systems so that testing criteria can be more accurately tailored to the actual operational requirements. For example, it may be possible to satisfy the purposes of testing some types of spacecraft by subjecting only samples of their materials and selected small parts to vacua in the range of 10^{-14} torr whereas the entire spacecraft itself will be adequately tested at the easily attainable vacuum of 10^{-6} torr.

This latter approach offers a potential alternative to testing a complete large sized space system. That is a "build-up" technique to develop criteria for testing materials, parts, and subsystems on a sufficiently rigorous basis, that analytical procedures can be used to evaluate the completely integrated system to such a high degree of accuracy as to abrogate the need for full scale system testing. We are a long way from achieving this ideal, but advancing technology should bring us much closer to its realization in the future.

Scale model techniques are under serious study as a tool to be used in the design development phase of space systems. Structural dynamic modelling already is well advanced thanks to the successful development of flutter models for aircraft. Some of the more difficult problems of thermodynamic modelling such as joint conductance, appear to be on the threshold of solution. Even magnetic modelling is being carefully considered. The main goal is to define the practical limitations of all these environmental modelling techniques and to use them within their useful context in complementing and validating other engineering approaches.

5. It is concluded that the environmental simulation needs generated by future space systems and operational functions will produce the following trends in laboratory testing:

a. Develop techniques to minimize the need for testing complete full scale space systems in environmental simulators.

b. Refine environmental scaling laws and acquire complete understanding of environmental effects so that the system "build-up" technique and scale modelling can be used to complement each other in early phases of evolving space system designs.

c. Categorize test parameters and procedures to fit specific operational requirements at appropriate levels of space systems integration. That is, separate materials evaluation from parts testing; parts testing from subassembly testing; subassembly from system testing, etc.

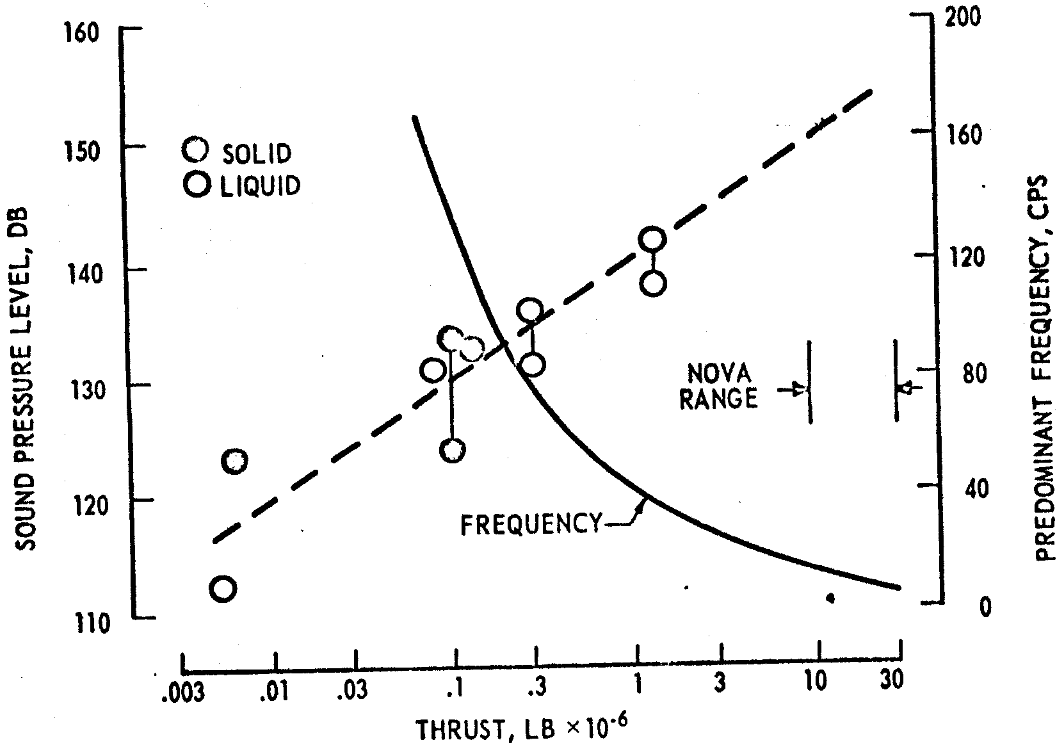
Several problems must be solved and voids remain to be filled before environmental simulation technology can meet tomorrow's needs:

a. Solar simulation techniques must be improved to produce closer correlation of thermal effects between ground test and space operation. Improved spectral match and correlation factors between lamps and solar radiation, improved measurement techniques, and more accurate control of sources will contribute to the solution.

b. Thermal and dynamic conductance of joints must be better understood to permit the cause-effect relationships pertaining to launch and space environments to be controlled by deliberate and inherent design of space systems.

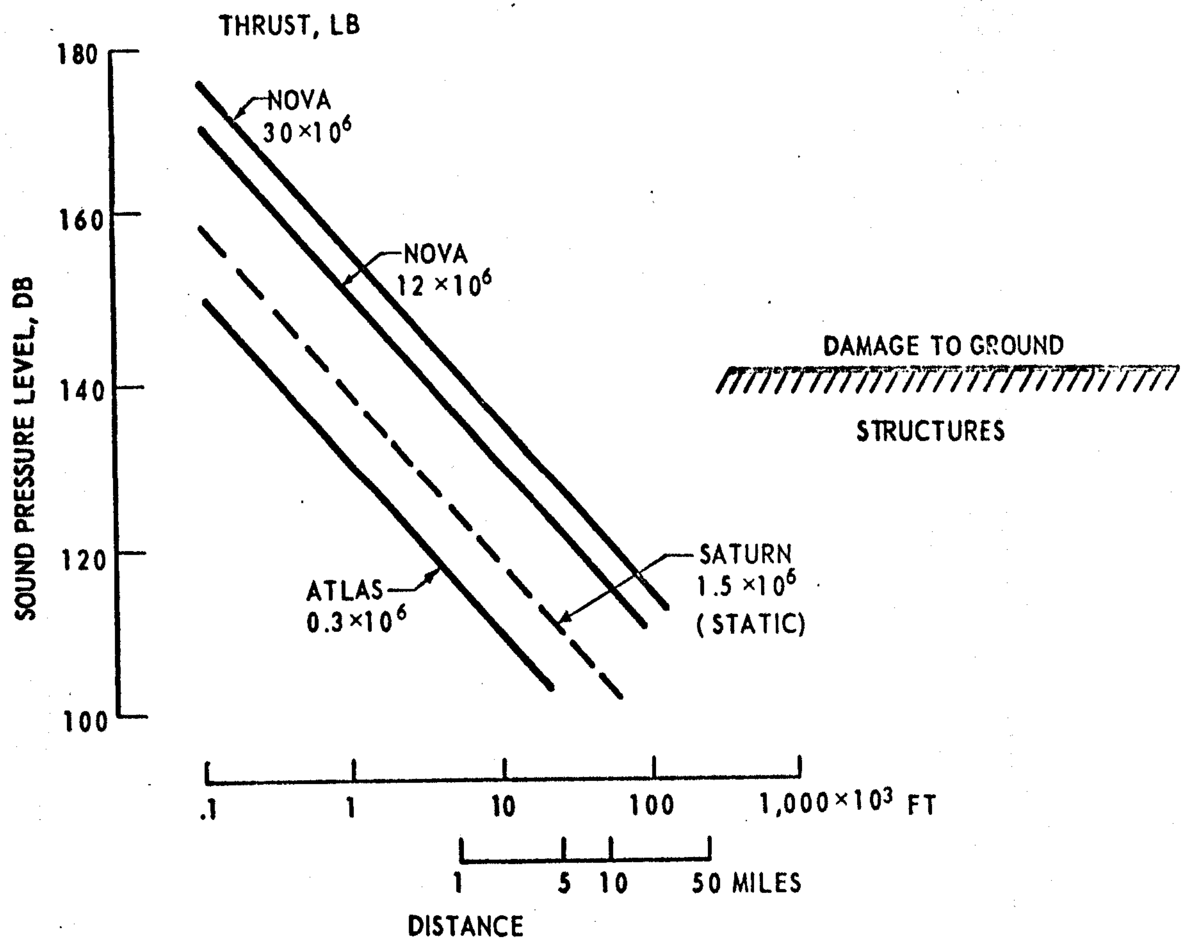
c. Adequate analytical and experimental methods of handling non-linear complex systems excited by non-stationary forces must be developed. A clear assessment must be made of what problems with respect to large rockets will be encountered in the impingement of intense low frequency sound energy on large sprawling structures and thin shells of future space systems.

6. Data to be used to substantiate conclusions are based primarily upon environmental simulation tests and experimental investigations, such as: outgassing vs. pressure acquired from a spacecraft thermal-vacuum test to illustrate a typical vacuum chamber "load"; analytical vs. experimental temperature distribution in a spacecraft subjected to solar simulation to show reasonable validity of present approaches; extrapolated data showing acoustic energy levels at low frequency for future large rockets; measured spectral distribution of Hg-Xe solar lamps for comparison with solar spectrum; radiation degradation of solar cells as an indicator of simulation requirements for space particle radiations.



Ref: Duberg, John E., Langley Research Center, "Space Vehicle Environment and Some NASA Facilities for their Simulation," paper presented at 31st Symposium Shock, Vibration, and Associated Environments, Phoenix, Arizona, October 1-4, 1962.

Figure 2. Sound Pressure Levels and Predominant Frequencies at 1,000 Feet from Rocket Engine

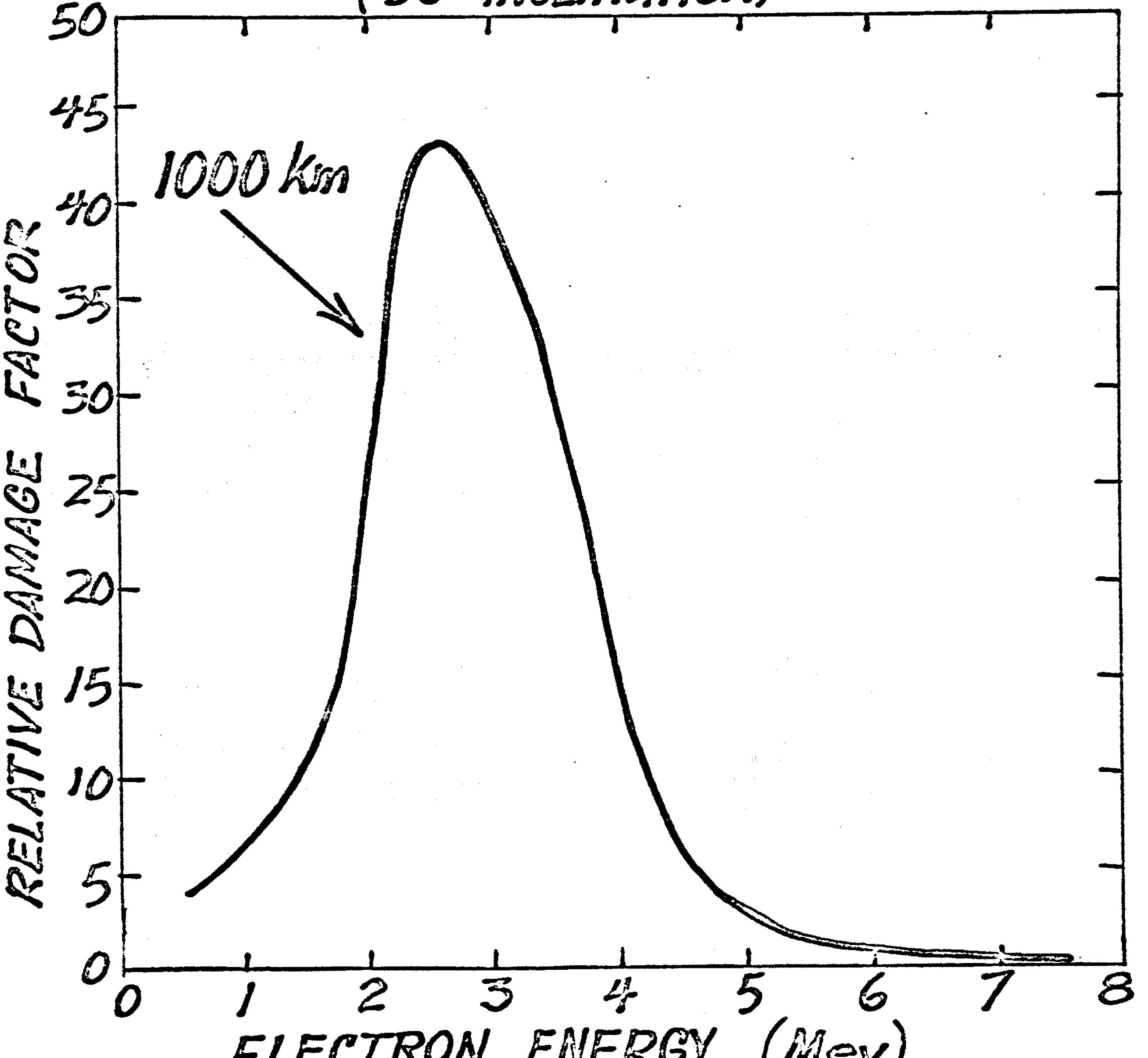


Ref: Duberg, John E., Langley Research Center, "Space Vehicle Environment and Some NASA Facilities for their Simulation," paper presented at 31st Symposium on Shock, Vibration, and Associated Environments, Phoenix, Arizona, October 1-4, 1962.

Figure 3. Noise Levels as a Function of Distance for Large Vehicles

RELATIVE ELECTRON DAMAGE TO SILICON SOLAR CELLS

WEIGHTED BY THE SPACE RADIATION SPECTRUM (30° INCLINATION)

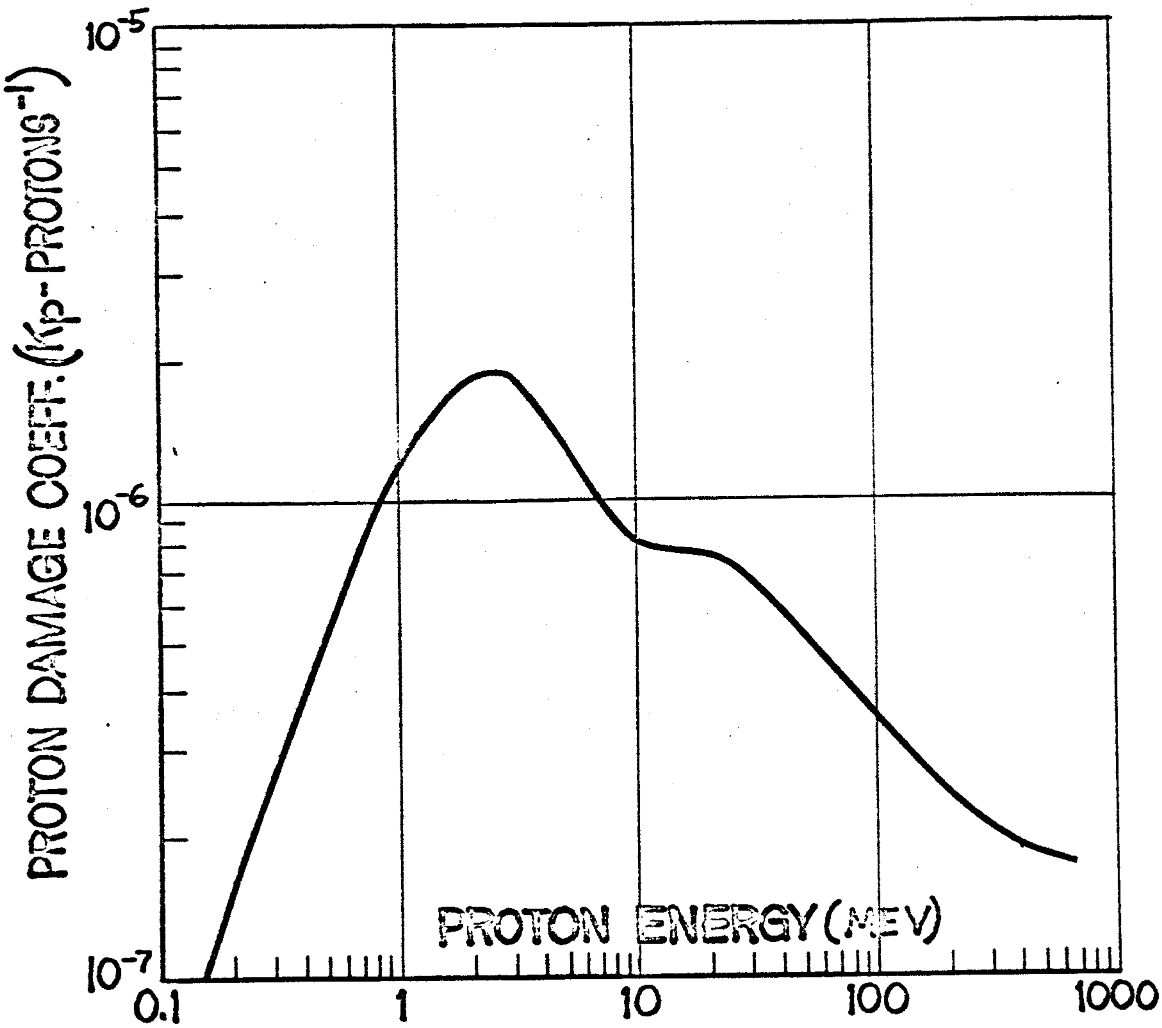


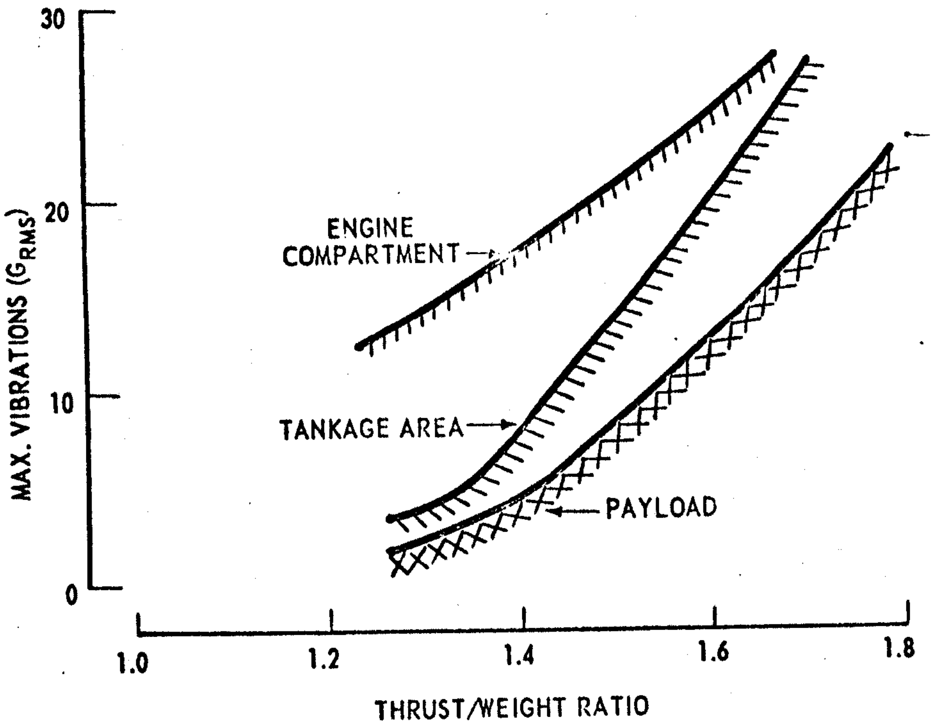
PROTON DAMAGE COEFFICIENT vs. PROTON ENERGY

N/P SILICON SOLAR CELLS 1 Ω-cm

EXPERIMENTAL DATA:

HANDBOOK OF SPACE RADIATION EFFECTS ON SOLAR CELL PWR SYSTEMS
Cooley and Janda NASA SP 3003
(DATA BELOW 3 MEV FROM LOCKHEED MISSILES AND SPACE COMPANY (UNPUBLISHED)





Ref: Brooks, George W., Langley Research Center, "Space Payload Vibration" paper presented to Aerospace Industries Association Symposium, December 6-8, 1962.

Figure 5. Maximum Launch Vehicle Vibrations During Lift-off

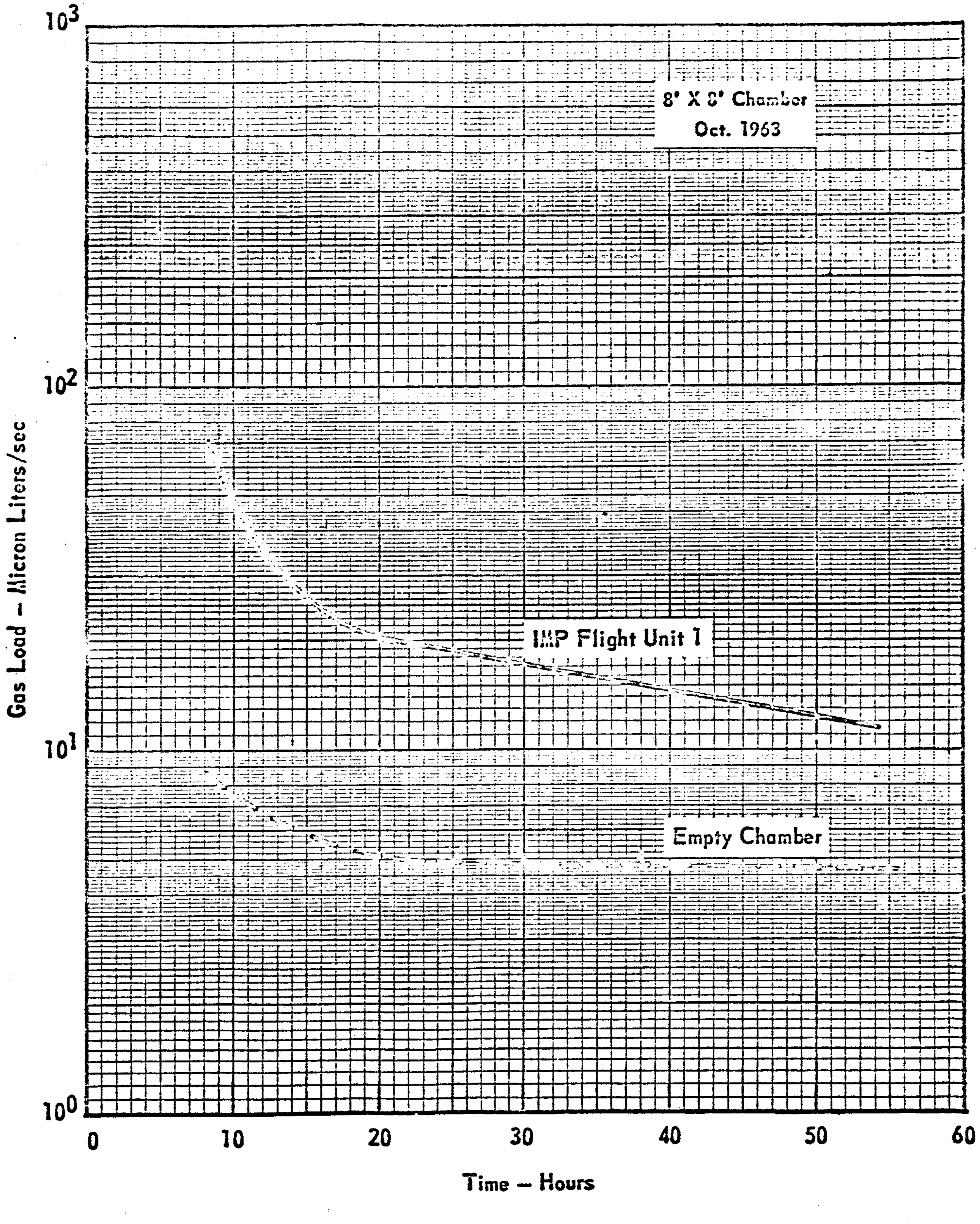


Figure 5. Gas Load Vs Time Curves for IMP Cold Test at –10°C

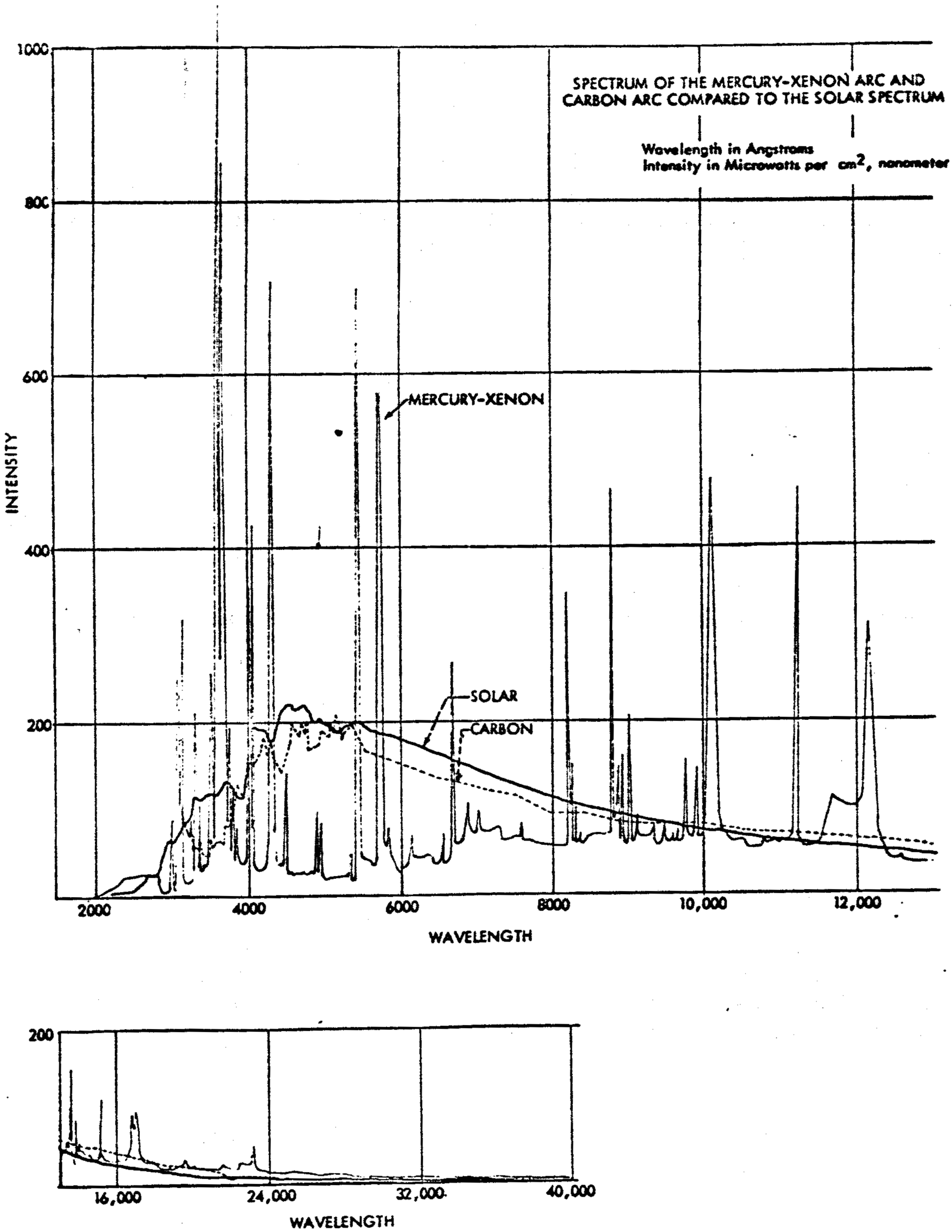


Figure A-5—Spectrum of the Mercury-Xenon Arc and Carbon Arc Compared to the Solar Spectrum .

about 10 degrees half-angle. A small part of the beam is focused by a biconvex quartz lens on the slit of the spectrograph. The f-number of the lens is such that the beam of light falling on the first concave mirror of the spectrograph does not fully cover the mirror. Thus the scattered light within the spectrograph is reduced to a minimum.

The Perkin-Elmer quartz-prism double-pass monochromator was used for most of the charts of the carbon arc. All measurements of energy were made from these charts. For detailed study of the highly complex line structure in the visible region of the spectrum, a few charts were made using the high-dispersion Jarrell-Ash grating spectrograph.

The carbon-arc spectrum has in the range 3500 to 7000A many times more emission lines than the mercury-xenon arc. All lines have a finite half-width. The lines are so close together that, even with a high-dispersion instrument, only the peaks of the lines are distinguishable. Figure A-6 gives a typical portion of the chart made with the Jarrell-Ash spectrograph. As many as 400 lines may readily be counted in this 1000A range from 4000 to 5000A. The wavelength scale is linear. The intensity values on the y-axis were taken from Perkin-Elmer charts made in the same region on a similar but different carbon arc; these values are an approximation.

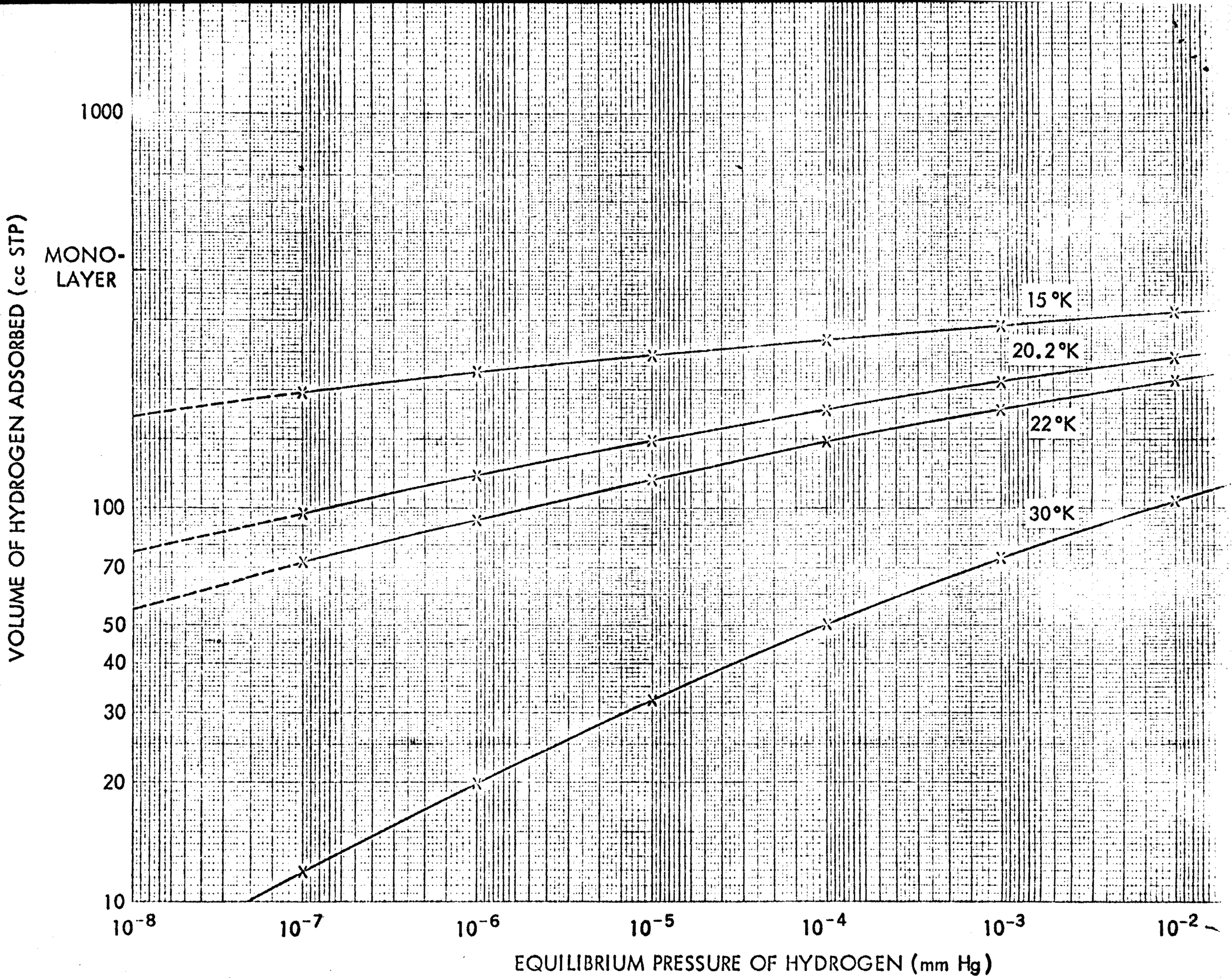
Beyond 5800A there are hardly any emission lines, and the spectrum chart is similar to that of a tungsten-ribbon lamp.

For measurement of energy, the charts were divided into short wavelength ranges, each corresponding to ten counts of the drum which controls the Littrow mirror. In each range a sloping line was drawn to indicate the average pen deflection of the range. Signal strengths were measured at the middle of these lines. The signal strengths of different charts and different gain factors were reduced to a common scale, using the conversion table for signal strengths previously noted (Table A-6).

For the other steps in data-reduction,energy calibration of the spectrograph, normalization to the solar constant, and integration of energy in wavelength ranges of 50, 100, 1000A, the procedure described for the Hg-Xe arc was followed.

The final results of two series of carbon-arc measurements are given in Table A-10. Wavelength is in angstroms. The intensity is in units of microwatts per angstrom range incident per cm^2 placed at such distance from the arc that the total energy received by the surface is 0.1396 watts.

Two columns of energy values are given in Table A-10 following the wavelength column. The first column refers to a new type of carbon rod, Lorraine Orlux, which only recently became commercially available. It is claimed that this type of rod gives relatively more energy in the visible and ultraviolet; our measurements show that the claim is justified to a certain extent. However, more reliable data in the range below 3100A are needed. The second column refers to the National Orotip cored carbon rods which are widely used in solar simulators.


VOLUME OF HYDROGEN ADSORBED (cc STP)
1000
MONO-LAYER
100
70
50
40
30
20
10
15 °K
20.2 °K
22 °K
30 °K
10^-8
10^-7
10^-6
10^-5
10^-4
10^-3
10^-2
EQUILIBRIUM PRESSURE OF HYDROGEN (mm Hg)